Energy Policy 127 (2019) 87–101

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Review and assessment of energy policy developments in Chile

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ARTICLE INFO

Keywords:
Climate Change
Energy Policy
Sustainable Energy Planning
Chile

ABSTRACT

In recent years, the Chilean energy sector has gone through a significant transformation. Chile ratified the Paris Agreement in 2017 and committed to develop policies to face climate change and to transition to a more sustainable energy system. Promoting renewable energy and energy efficiency became an essential strategy for Chile to reduce emissions and reach its energy and environmental goals, which are addressed in various governmental studies. Further, Chile became successful in promoting renewable electricity production without feed-in tariffs. The current national goal is for at least 70% of the electricity in Chile to be generated from renewable energy sources by 2050. Additionally, energy efficiency is to be implemented in several sectors. This paper provides a broad overview of the energy sector and review of the Chilean energy policy development and environmental targets with emphasis on recent years. Finally, it also proposes an assessment about existing and required energy policy instruments for Chilean energy sectors by considering the promotion of renewable energy and energy efficiency and analyses the associated potential challenges. This work can provide insights to decision makers to develop long-term sustainable energy plans for Chile to reach its energy and environmental goals.

1. Introduction

According to the BP Review of World Energy, approximately 85% of global energy demand is met by fossil fuels including oil, coal, and gas (British Petroleum, 2017). High demand growth, uncertain fuel price, and the rising concern about climate change force countries to have long-term, cost-effective, secure, and sustainable energy policies and long-term planning. Thus, many industrialized and developing countries have started to change their future energy plans towards de-carbonization.

One hundred and seventy-eight countries ratified the Paris Agreement to share the responsibility for the consequences of climate change, and they have been working on various solutions towards a sustainable future ("Paris Agreement - Status of Ratification," n.d.). In August 2010, Chile officially made a voluntary commitment to the United Nations that states, "Chile will take mitigation actions in order to achieve a deviation of 20% below its growing trajectory of business-as-usual emissions in 2020, projected from the year 2007" (Gobierno de Chile, 2013). In February 2017, Chile ratified the Paris Agreement and committed to developing policies on climate change and to achieve sustainable development objectives. In the scope of this agreement, Chile proposed a target that represents a reduction of 30% in greenhouse gas (GHG) emissions below 2007 levels by 2030, and also to apply carbon taxes of USD 5/tCO2 for fixed turbines or boilers above 50 MW_{th} (The Committee of Ministers for Sustainability and Climate Change, 2015). In addition to signing international agreements, Chile also set targets at the national level. According to the Law of Electrical Services, modified by Law N° 20.936, every five years the Chilean

Abbreviations: BAU, Business as usual; BNE, Balance Nacional de Energía; BP, British Petroleum; EU, European Union; FITs, Feed-in-Tariffs; GDP, Gross Domestic Products; GHG, Greenhouse Gas Emissions; INDCs, Intended Nationally Determined Contributions; MAPS, Mitigation Action Plans and Scenarios; Mtoe, Million Tonnes of Oil Equivalent; NEB, National Energy Balance; NDCs, Nationally Determined Contributions; NG, Natural Gas; OECD, Organization for Economic Co-operation and Development; PV, Photovoltaic; R&D, Research and Development; RBS, Required by Science; SEA, Aysen Electricity System; SEM, Magallanes Electricity System; SEN, National Electricity System; SING, Northern Interconnected System; SIC, Central Interconnected System; TPES, Total Primary Energy Supply; UNFCCC, United Nations Framework Convention on Climate Change

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https://doi.org/10.1016/j.enpol.2018.11.058
Received 8 August 2018; Received in revised form 29 November 2018; Accepted 30 November 2018
Available online 11 December 2018
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Ministry of Energy will have to develop a long-term energy plan for different energy scenarios that include expansion of generation and energy demand, in a horizon of at least thirty years (Ministerio de Energía, 2017).

Additionally, Chile has significant renewable energy potential, which can contribute to the sustainability of future energy plans. The north of Chile has the best worldwide solar energy potential for energy generation, on account of dryness and clear sky (Escobar et al., 2015, 2014). Also, industry in the north of Chile is based on highly energy-intensive mining activities (Del Sol and Sauma, 2013).

This paper presents a comprehensive overview of the energy sector and review of energy policy development in Chile with an emphasis in the last eight years. The objective of the study is to evaluate the current energy policy of Chile to reach future energy targets by assessing policy instruments and studying existing challenges. The paper makes four contributions to the literature: i) It provides a broad overview of the Chilean energy sector by considering energy demand, generation mix, renewable energy potential, and the economic context. ii) It addresses the question of how energy policies in the last decade have been developed in Chile. iii) It summarizes the environmental commitments and main long-term energy targets of Chile and iv) it proposes an assessment about existing and required energy policy instruments for Chile by considering the promotion of renewable energy and energy efficiency to reach future energy goals and studies the various associated challenges.

The paper is organized as follows: Section 2 presents the methodological approach of the paper including the review and assessment processes. Section 3 includes an overview of the energy sector in Chile by considering energy access and sectors, characterization of energy demand and supply, renewable energy potential and generation, and the economic context. Section 4 describes energy policy development in Chile and actions taken by the government since 2011. Section 5 reviews the nationally determined contributions and principal energy targets of Chile. Section 6 presents a thorough assessment and discussion of energy policy instruments in terms of deployment of renewable energy and energy efficiency for Chile, as well as several challenges for the future of the Chilean energy sector. Finally, Section 7 concludes the paper and discusses future works.

2. Methodology

This research mainly has a two-part methodology including literature review and assessment. The cross-functional flowchart of the methodology is presented in Fig. 1. For the overview and review sections, a systematic review of the literature was realized by utilizing relevant keywords (both in Spanish and English languages) in two scientific search engines (Science Direct and Google Scholar), Chilean governmental and non-governmental websites and energy-related international agencies. Also, in the section of current energy policy review, the years between 2011 and 2018 were chosen and reviewed due to significant developments in energy policy in Chile along that time. Moreover, nationally determined contribution and principle energy targets of Chile were revised and summarized to understand the future energy policy.

From all analysis of these reviews, it is understood that in parallel to the world, renewable energy promotion and energy efficiency will help Chile to reach its national and international targets. Therefore, the assessment in this paper seeks to clarify "*what are*" the current energy policy instruments related to renewable energy and energy efficiency in Chile by comparing the situation with respect to the rest of the world and also it seeks to identify "*what should be considered in the future*" by taking into account Chilean mining, industry, residential, transportation, public and commercial sectors. This analysis was realized in order to understand the contribution of current and required renewable energy and energy efficiency policy instruments to the future energy targets. Finally, after the assessment process, potential future energy policy challenges were determined to show and emphasize how future policies should be directed for Chile by decision-makers in the last part of the discussion section.

3. Overview of the energy sector in Chile

3.1. Energy access and sectors

Chile has a unique geography due to its long and narrow shape. It is divided into fifteen regions from north to south. Until the end of 2017, Chile had four main electricity grids: the Northern Interconnected System (SING), the Central Interconnected System (SIC), the Aysen System (SEA), and the Magallanes System (SEM). Between these four grids, SIC and SING have the major capacity share with 75.8% (17081 MW) and 23.5% (5288 MW), respectively (CNE, 2017). In 2018, SING and SIC were combined, and the newly combined grid is now called the National Electricity System (*Sistema Electrico Nacional*-SEN). SEN encompasses thirteen regions and controls 99% of the total electricity supply of Chile, as shown in Fig. 2 (CNE, 2018a).

In the northern regions, oil and natural gas are the main sources, while biomass (mostly firewood) has an important share in the southern part of the country. The energy supply has diversified in recent years with the inclusion of renewable energy, and the primary energy supply of Chile consists mainly of oil, coal, natural gas, biomass, hydro, solar, and wind sources. These sources are consumed in five main sectors: industry, mining, commercial and public, residential, and transport. Industry and transport constitute the biggest shares in the total consumption of energy, and mining activities, which take place in the northern regions of Chile (Ministerio de Energía, 2015a; Ministerio de Energía División de Prospectiva y Política, 2018), are also heavily energy intensive.

3.2. Characterization of energy supply and demand

Chile mainly depends on imports for its domestic energy supply; the proportion was approximately 65% in 2016. The total primary energy supply (TPES) reached approximately 32 million tons of oil equivalent (Mtoe) in 2016, as shown in Fig. 3.

Oil is the principal energy source, followed by biomass (mainly firewood), coal, natural gas, and hydro, respectively, as presented in Fig. 4. The fossil fuel share of TPES is roughly 68%, which includes oil (29%), coal (24%), and natural gas (15%). Moreover, renewable energy has an essential contribution to TPES (32%); this source included biofuels and waste (25%), hydropower (6%), and wind and solar energy (1%) in 2016 (Ministerio de Energía División de Prospectiva y Política, 2018).

The total energy consumption corresponds to the energy destined for the consuming sectors of the national economy, both for energy and non-energy use. This total energy consumption in 2016 was 28.5 Mtoe, while it was 27.7 Mtoe in 2015. As illustrated in Fig. 5, oil and electricity constitute a significant share of total consumption, and transportation and industry also constituted major shares of total energy consumption among other sectors in 2016.

As mentioned above, only 35% of Chile's domestic energy needs are met by self-sufficiency; the rest are dependent on imported resources. Almost 98% of the necessary oil, 77% of natural gas, and 80% of coal were imported in 2016. Although natural gas and coal importation shares have fluctuated significantly depending on suppliers, oil has remained almost the same since 1990 (IEA, 2018; Ministerio de Energía División de Prospectiva y Política, 2018).

In 2016, the consumption of electrical energy, from both the power plants connected to the different interconnected systems and from the self-producing companies, varied by 3.9% with respect to 2015 electricity consumption (6.0468 Mtoe) and reached 6.2851 Mtoe. In Fig. 6, total electricity consumption by sector is compared for 2015 and 2016. These show a similar tendency, and by 2016, electricity was consumed

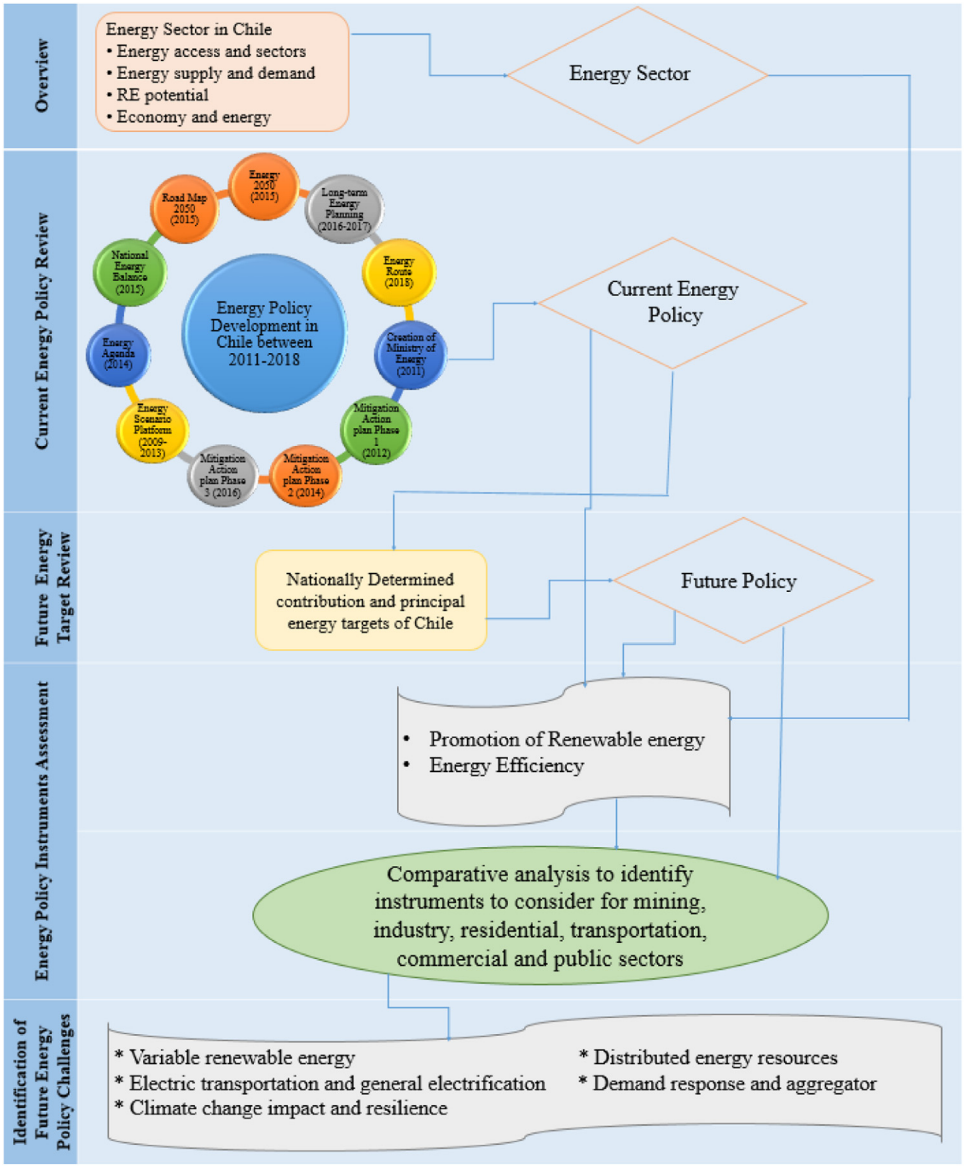

Overview
Energy Sector in Chile
• Energy access and sectors
• Energy supply and demand
• RE potential
• Economy and energy
Energy Sector
Current Energy Policy Review
Energy Policy Development in Chile between 2011-2018
Road Map 2050 (2015)
Energy 2050 (2015)
Long-term Energy Planning (2016-2017)
Energy Route (2018)
Creation of Ministry of Energy (2011)
Mitigation Action plan Phase 1 (2012)
Mitigation Action plan Phase 2 (2014)
Mitigation Action plan Phase 3 (2016)
Energy Scenario Platform (2009-2013)
Energy Agenda (2014)
National Energy Balance (2015)
Current Energy Policy
Future Energy Target Review
Nationally Determined contribution and principal energy targets of Chile
Future Policy
Energy Policy Instruments Assessment
• Promotion of Renewable energy
• Energy Efficiency
Comparative analysis to identify instruments to consider for mining, industry, residential, transportation, commercial and public sectors
Identification of Future Energy Policy Challenges
* Variable renewable energy
* Electric transportation and general electrification
* Climate change impact and resilience
* Distributed energy resources
* Demand response and aggregator

Fig. 1. Cross-functional flowchart of the methodology.

mainly by the mining sector (34%), industry (27%), the residential sector (17%), and the commercial and public sector (16%) (Ministerio de Energía División de Prospectiva y Política, 2018).

3.3. Renewable energy potential and generation

Chile has remarkable potential for renewable energy. The country's northern region has one of the best worldwide solar energy potentials to generate electricity due to its dryness and clear sky (Escobar et al., 2015, 2014). In the north of the country, there are heavily energy-intensive mining activities, which consume 99% of the electricity generation in the region (Del Sol and Sauma, 2013). According to a joint study by the Ministry of Energy and the German Agency for International Co-operation in 2014, solar photovoltaic (PV) potential was estimated at 1263 GW, concentrated solar power at 548 GW, wind power at 37 GW (capacity factor of at least 30%), and small hydropower at 12 GW (IEA, 2018; Santana et al., 2014).

In addition to these, it was estimated that Chile has a potential of 164 GW from the ocean due to its long Pacific coast, 16 GW from geothermal sources because of containing 10% of the most active volcanoes in the world, and 1.4 GW from biomass sources (Woodhouse and Meisen, 2011). Fig. 7 shows the share of sources for total energy sources between the years 1973 and 2016. From this figure, it can be observed that the shares of hydropower and biomass have been very constant throughout the years 1973–2016. Additionally, despite the huge solar and wind potential, the contribution of these sources to the national energy balance appeared after 2010. In 2016, renewable energy shares, including biomass, hydro, wind, and solar, reached 34% of TPES. Besides transferring solar electricity from the north to the centre of Chile, researchers are investigating the possibility of solar electricity production and transmission to neighbouring countries such as Argentina and Bolivia (Fthenakis et al., 2014).

The net installed capacity based on renewable energy technologies, including solar, wind, biomass, geothermal, and mini-hydro (hydro less than 20 MW capacity) (Ministerio de Economía, 2013) totalled 4110 MW as of December 2017, including 3443 MW in the SIC, 637 MW in SING, 26 MW in the electric system of Aysen, and 3 MW in Magallanes. In Fig. 8, the total installed capacity of wind and solar energy sources in Chile between the years 2011 and 2017 is shown. It can be observed that solar and wind energy have a significant contribution to the renewable energy matrix in the most recent years (Grágeda et al., 2016; Zurita et al., 2018). Although wind energy projects were started

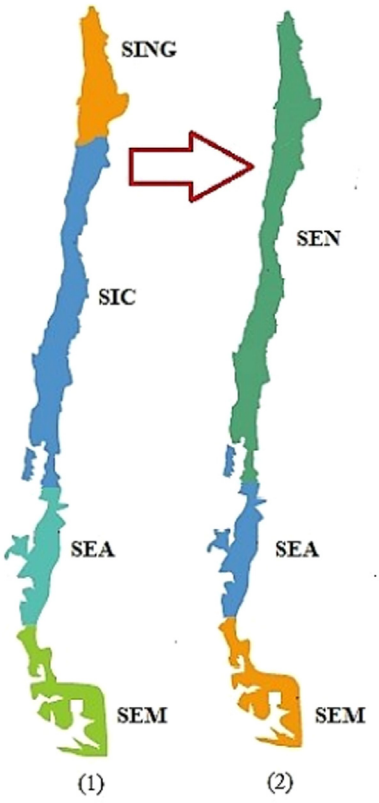


Fig. 2. National electricity grid in Chile (1); until December 2017 (2); after connecting SING and SIC as SEN in 2018. (Figure constructed based on references (CNE, 2017, 2018a).).

in early 2011, solar energy caught the wind at the end of December 2016, and solar energy surpassed wind energy in Chile.

The installed renewable energy capacity corresponds to 18% of the total electrical generation capacity in the national electricity systems, in which mini-hydro has 2%, biomass has 2%, wind has 6%, and solar has 8%. Besides installed capacity, renewable energy generation reached 1146 GWh while energy generation was 5530 GWh from conventional

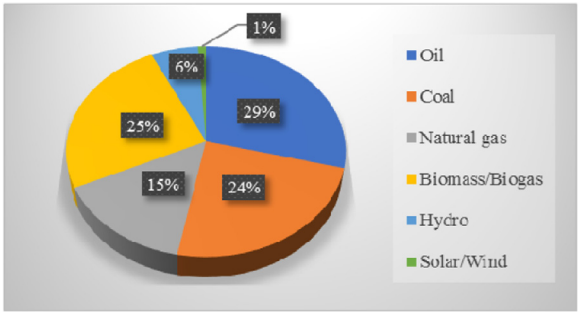


Fig. 4. Primary energy matrix in 2016. (Figure constructed based on reference (Ministerio de Energía División de Prospectiva y Política, 2018).).

energy sources, as shown in Fig. 9. Solar PV, wind, and biomass have had a significant contribution to generation in the most recent years (CNE, 2018b).

3.4. Economy and energy context

The current population of Chile is approximately 18 million. Access to electricity for the urban and rural population has now reached 100% while it was only 92% in 1990 (The World Bank, 2018). In 2017, the country's GDP was 23,476 USD/capita, which was 115% higher than that in 1996 (IEA, 2018; OECD, 2018a), and the unemployment rate was 6.7%, which is more than the average of OECD countries (OECD, 2018b). Chile's copper resources are roughly 29% of the world's copper reserves, and it is the largest copper producer and exporter, having produced 37% of the world's copper in 2016. Thus, fluctuations in the global copper market affect Chile's national economy considerably. Although copper prices dropped dramatically from 2012 to 2016, the contribution of copper mining to the economy is still high, constituting 7.3% of GDP in 2016 (IEA, 2018; OECD, 2018c).

Due to Argentina's curtailing of natural gas exports to Chile, electricity prices for both households and industry reached the highest prices in 2008. After Chile spread energy sources out, especially by increasing electricity generation from coal, electricity prices started to drop. In the last years, prices have also fluctuated again due to changes in tariffs and tender results after the gas crisis. In 2016, electricity prices were approximately 120 USD/MWh and 170 USD/MWh for

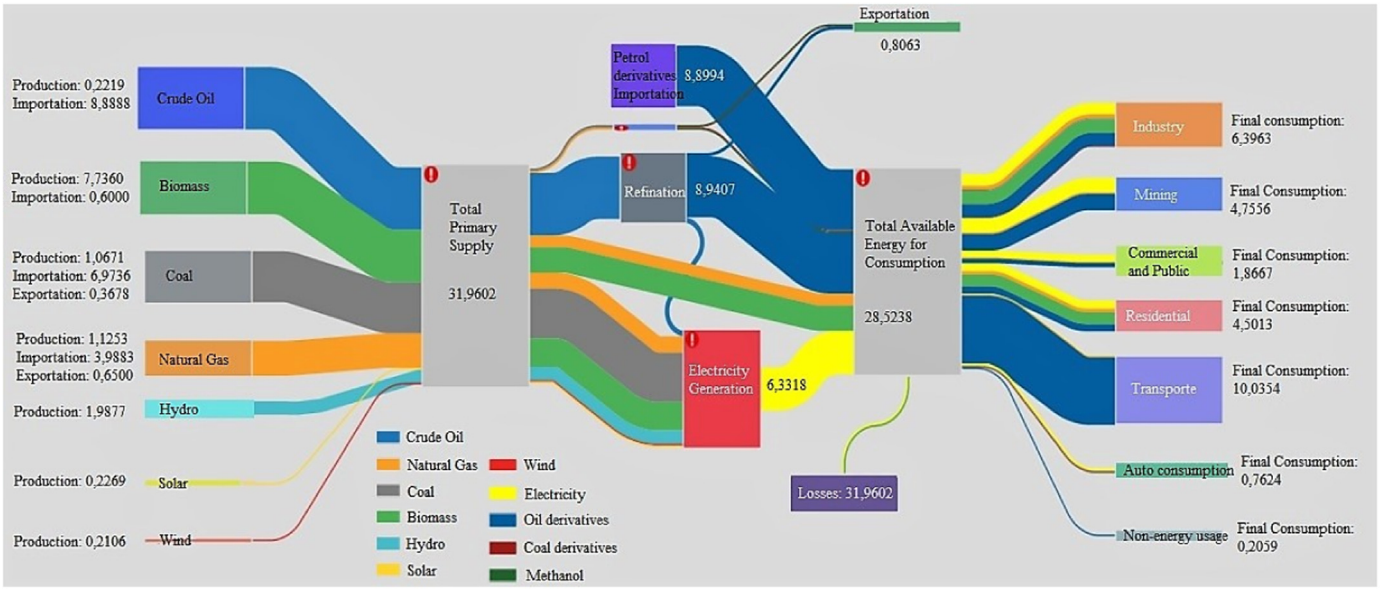


Fig. 3. The national energy balance of Chile in 2016 (all units in Mtoe). (Figure translated into English for this paper based on reference (Ministerio de Energía División de Prospectiva y Política, 2018).).

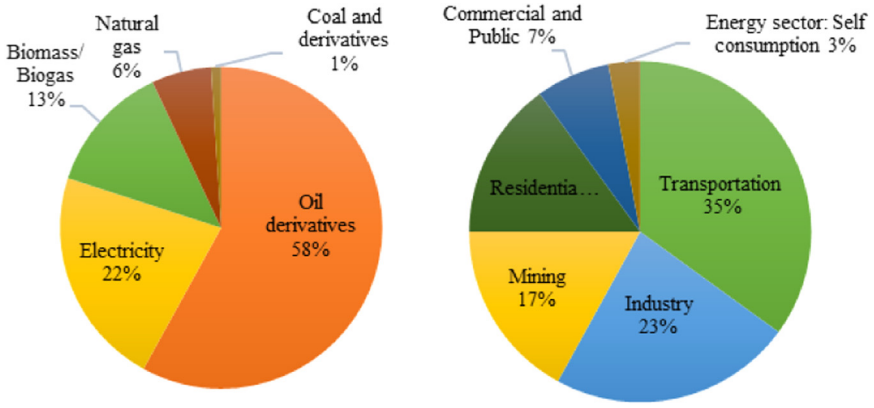


Fig. 5. Total energy consumption by sources (left) and sectors (right) in 2016. (Figure constructed based on reference (Ministerio de Energía División de Prospectiva y Política, 2018).).

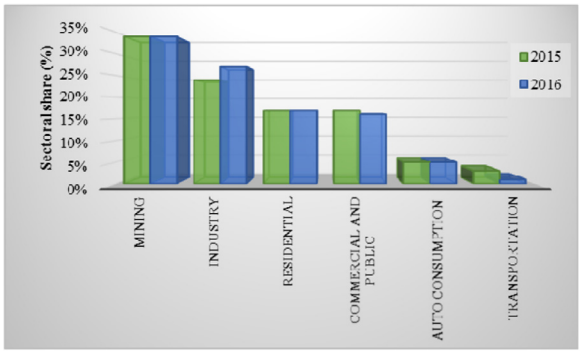


Fig. 6. Total electricity consumption by sector, 2015 and 2016. (Figure constructed based on reference (Ministerio de Energía División de Prospectiva y Política, 2018).).

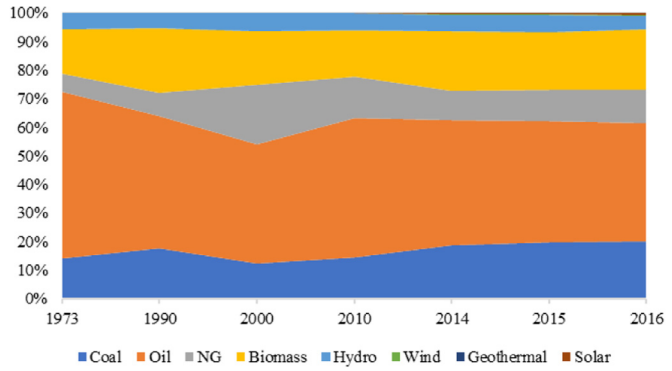


Fig. 7. The share of sources in TPES, 1973–2016 (Mtoe). (Figure constructed from data in (IEA, 2018).).

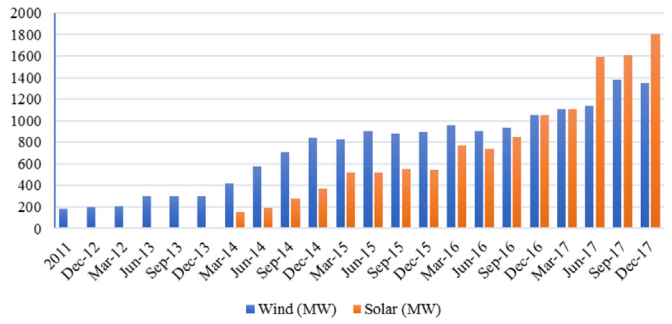


Fig. 8. The total installed capacity of wind and solar energy in Chile, 2011–2017. (Figure constructed from data in reference (CNE, n.d.).).

industry and household sectors, respectively (IEA, 2018).

4. Energy policy development in Chile between 2011 and 2018

The Ministry of Energy was created with law No. 20.402 in February 2010, and it obtained autonomy by being separated from the Ministry of Mining (Biblioteca del Congreso Nacional de Chile, 2012a; Congreso Nacional de Chile, 2009). Activities related to long-term energy planning in Chile have gained momentum and accelerated after the establishment of the energy ministry. Along with other worldwide developments related to climate change, Chile has begun to take decisive steps. Each of these developments is described in the remainder of this section.

4.1. The mitigation action plans and scenarios: MAPS-Chile project (2011–2016)

The MAPS-Chile project originated following the example of a project carried out in South Africa. This South Africa project was the original MAPS project and motivated also other projects in countries including Brazil, Colombia, and Peru (Gobierno de Chile, 2014, 2013).

MAPS-Chile was a government project that developed projections and mitigation action plans to reduce greenhouse gas emissions in Chile (Gobierno de Chile, 2013, 2012; Ministerio del Medio Ambiente (Mitigation Action Plans and Scenarios), 2011). The project was started in 2012 and managed by an Inter-Ministerial Committee. It was carried out in three phases. During Phase 1, the projection of the baseline scenario for 2007–2030, or the *Growth without restrictions* and *Required by science* scenario, was carried out. In Phase 2, in development until the end of 2013, the baseline scenario for 2012–2030 and the different mitigation scenarios were projected. Finally, in Phase 3, all results were combined and interpreted for mitigation action plans (Gobierno de Chile, 2013). The growth without restrictions scenario does not consider any emission reduction actions and the energy policies continue as they are. The baseline scenario for 2012–2030 takes into the account year 2012 as the base year and includes several mitigation actions. The scenario Required by Science (RBS) allows Chile to meet the global goal of stabilization of global emissions to limit the increase in the average temperature of the terrestrial surface to less than 2 °C above pre-industrial levels, in order to avoid the most dangerous effects of climate change (Gobierno de Chile, 2013, 2012). In the following sections, three phases of MAPS are explained and summarized in details.

4.1.1. MAPS: Phase 1

In the first phase of the project, five different GHG emissions scenarios were developed for 2007–2030. In order to generate scenarios, key assumptions were determined. Besides the reference scenario, the

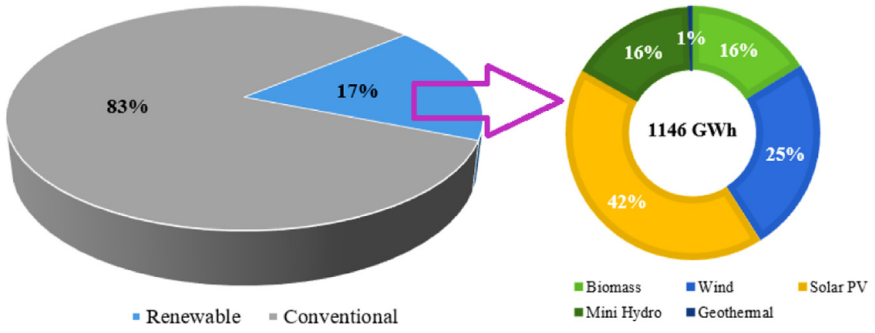


Fig. 9. Renewable and conventional energy generation by technology, until December 2017. (Figure constructed from data in (CNE, 2018b).).

projection of the GDP growth rate for the years 2007–2030 was determined by four scenarios:

- GDP pessimistic scenario: 3% growth rate
- GDP medium-low scenario: 4% growth rate
- GDP medium-high scenario: 5% growth rate
- GDP optimistic scenario: 6% growth rate

Fig. 10 shows GHG emissions for five different scenarios between 2007 and 2030. GHG emission values for 2030 were obtained as follows: 214.8 MM ton CO2eq for GDP reference scenario, 175.4 MM ton CO2eq for GDP pessimistic, 223.0 MM ton CO2eq for GDP medium-low, 283.7 MM ton CO2eq for GDP medium-high, and 356.9 MM ton CO2eq for GDP optimistic scenario (Gobierno de Chile, 2013).

4.1.2. MAPS: Phase 2

In the second phase of the project, 2013 was taken as the base year, and the work was organized in a similar way to Phase 1. In this study, baseline scenarios, in which no mitigation was considered, were generated for the years between 2013 and 2030 and each sector's participation in total emissions of the baseline scenario were illustrated in the report. It was obtained that the generation/transport of electricity, transport, and industry/mining sectors make major contributions to total emissions.

After calculating the baseline 2013 scenario, the mitigation measures with the highest reduction potentials were presented for the 2013–2030 period. More than 96 mitigation measures for seven sectors were analysed; however, it was observed that 29 of them had more potential to contribute the highest reductions. The measures with the greatest abatement potentials for the 2013–2030 period were obtained for the generation/transport of electricity and transport sectors. To see the impact of measures on emission reductions, selected measures were combined and added to the baseline 2013 GDP medium scenario. Thus, more scenarios were developed, as follows (Gobierno de Chile, 2014):

- Energy efficiency (EE) scenario: Combination of mitigation measures related to energy efficiency.
- Carbon tax scenario: Considering the set of measures in which carbon taxes are applied.
- Non-conventional renewable energies (NCRE) scenario: Combination of all measures that include the incorporation of non-conventional renewable energies, among them solar, geothermal, wind, biomass, and small hydro.
- Renewable energies (RE) scenario: Combination of all the actions that include renewable energy from the NCRE scenario, plus large hydroelectric plants. This scenario considers, for example, the implementation of the HidroAysén project from the year 2021.
- 80/20 Scenario: Referring to a scenario that combines a reduced set of measures that adds a high mitigation potential.

In addition to these five special scenarios with mitigation measures determined, three more basic scenarios were considered in the analysis, as follows:

- Base scenario*:* considering 12.3% emissions reduction by 2030.
- Medium scenario*:* considering 29% emissions reduction by 2030.
- High scenario*:* considering 32.7% emissions reduction by 2030.

In conclusion, nine different scenarios are compared in Fig. 11. The emissions trajectory for these mitigation scenarios can be seen for the 2013–2030 period. The renewable energy, 80/20, medium, and high scenarios showed better results for emissions mitigation in 2030, while the energy efficiency, carbon tax, NCRE, and base scenarios produced fewer contributions to emissions reduction. Thus, the best mitigation measures were defined and their impacts were studied in the second phase of the MAPS-Chile project.

4.1.3. MAPS: Phase 3

The third phase of the MAPS-Chile project included several steps. First, refinements were realized for the work done during Phase 2. This included various revisions and iterations on the results already obtained from the previous stages. Additionally, an impact analysis was performed, which looked at the possible effects associated with the selected mitigation measures. Also, long-term mitigation analysis including a period until 2050 was considered in the third phase. Finally, public policy analysis was undertaken by considering the possibility of implementing the measures and the relationship between the

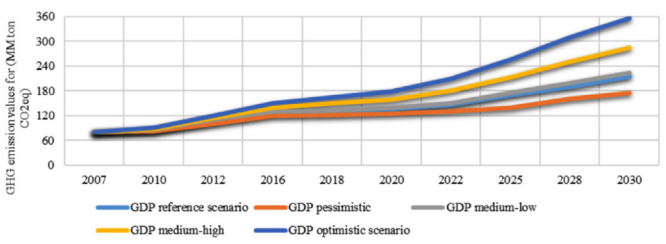


Fig. 10. GHG emissions for five different scenarios, 2007–2030, from the MAPS-Chile Phase 1 (Gobierno de Chile, 2013). (Figure constructed based on reference (Gobierno de Chile, 2013)).

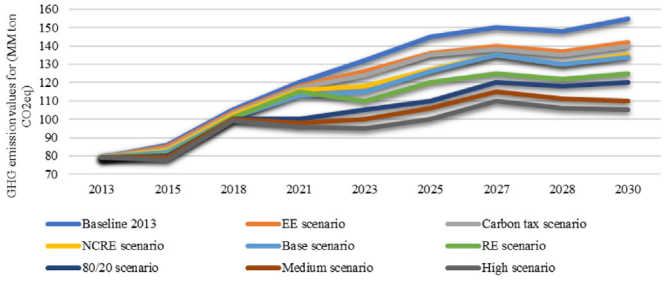


Fig. 11. Emission values of the year 2030 for the mitigation scenarios studied from the MAPS-Chile Phase 2 (Figure constructed based on reference (Gobierno de Chile, 2014)).

mitigation measures and the relevant sectoral policies (Ministerio del Medio Ambiente y Gobierno de Chile, 2016).

4.2. Energy Scenarios platform (2009–2013)

In addition to governmental studies, energy-related actors have come together and performed some studies for the long-term period. Energy Scenarios (originally Escenarios Energéticos) was a multi-sectoral dialogue platform in which key actors representing the diverse visions of Chilean society participated. It began in 2009 with two strategic objectives: the construction and discussion of different scenarios for electric energy generation by 2030, and the generation of tools for the formulation of a public energy policy (Escenarios energeticos, 2018). The members of the platform met regularly and developed a work plan and methodology during 2009 and 2010 (Centro de Energia; Universidad Adolfo Ibanez; EECG Consultores, 2017).

Then, in 2011, four scenarios were proposed for electricity expansion planning for the central (SIC) and northern (SING) interconnected systems of Chile until 2030. First, two projections were realized by considering that no radical change would be incorporated into the composition of the electricity matrix: Market Criteria SIC and SING, respectively. Other scenarios are called Renewable SIC and SING scenarios and corresponded to a vision where renewable energy had a high contribution to the electricity matrix. In the case of the SIC, a high penetration of geothermal energy, and for the SING, a high participation of solar energy was taken into account. (Dufey et al., 2013). The capacity share based on sources for 2030 are illustrated for each scenario in Fig. 12. As presented in the pie charts, the share of solar PV, wind and geothermal showed a significant increase in SIC while solar PV, solar CSP and natural gas play important role in the SING. Also, it is interesting to see that coal and diesel do not exist in the capacity share for 2030; high renewable penetration scenarios for SIC and SING.

4.3. Energy agenda (2014)

In 2014, the Energy Ministry of Chile decided to develop an agenda that included national action plans to have reliable, sustainable, inclusive, and reasonably priced energy. This agenda was urgent because Chile imported 60% of its primary energy in 2014, which meant high dependency on foreign resources. Therefore, with the energy agenda, a new role for the Chilean government and the goals were defined for future energy policy (Ministerio de Energía, 2014). This agenda was an essential step in terms of defining new roles for government and energy-related actors and also because of stabilizing the long-term energy planning in Chile.

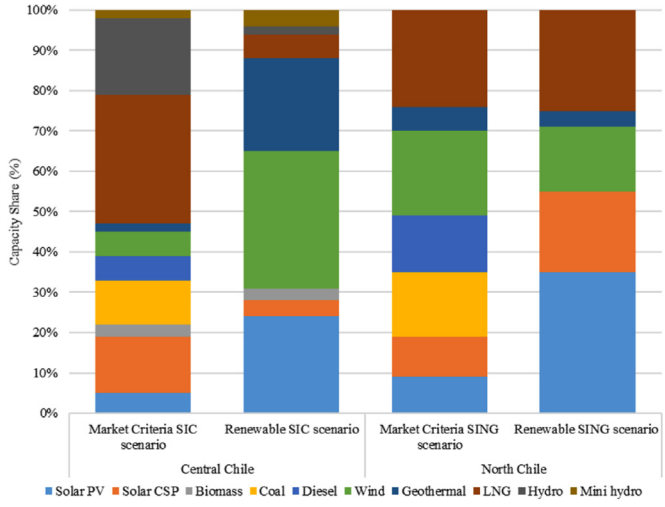


Fig. 12. The capacity share based on sources for 2030 in the study of the Energy Scenarios platform for the scenarios of Market Criteria and Renewable SIC and SING (Dufey et al., 2013) (Figure constructed based on reference (Dufey et al., 2013)).

4.4. National Energy Balance (2015)

After defining new roles and goals for future energy planning, an energy balance study was conducted by the Ministry of Energy in 2015. The National Energy Balance study (Balance Nacional de Energía) was a useful tool that explained the reality of the country's energy sector in an integrated and comparative way for 2015. The report also illustrated the different energy flows from production to consumption, as well as the sectoral and regional energy balance. This study provided an essential example for future long-term energy plans. The NEB flowchart summarizes the transactions involved in the national energy chain, from acquisition or generation to transformations and final consumption (Ministerio de Energía, 2015a).

4.5. Road Map 2050 (2015)

The Road Map (Hoja de Ruta) was a preparatory study for Energy Agenda 2050. The advisory committee, a group of twenty-seven experts from various fields related to the energy sector, worked for a year on the development of a roadmap towards a sustainable and inclusive energy future for Chile. It contained the key items of the long-term energy policy as promised in Energy Agenda. Thus, it contained the fundamental inputs to prepare Energy Agenda 2050: Chilean's Energy Policy (Comité Consultivo de Energía, 2050, 2015). As shown in Fig. 13, five sectors and five cross-cutting issues were considered with this guideline. Then, the strategic axes of the roadmap were determined as shown in the figure (Comité Consultivo de Energía, 2050, 2015).

Based on these strategic pillars, detailed targets, actions, goals for 2035 and 2050, and actors were established in the Road Map. Table 1 lists the main strategic action decisions of the plan. Detailed actions and goals for each pillar can be found in the original document. The highest number of actions were decided for the efficient use of energy and energy culture, sustainable energy, and relationship with communities and energy poverty. However, all strategic axes of Roadmap 2050 included essential actions, such as promotion of renewable energy, with a minimum of 70% by 2050, reduction of energy poverty, improvement of energy efficiency for transport (Comité Consultivo de Energía, 2050, 2015).

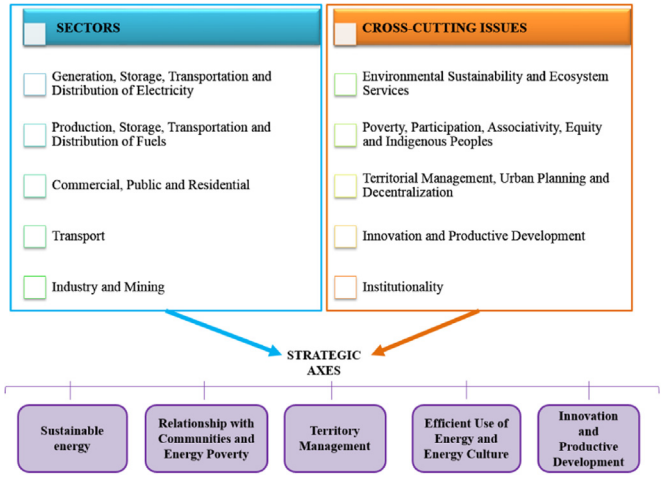
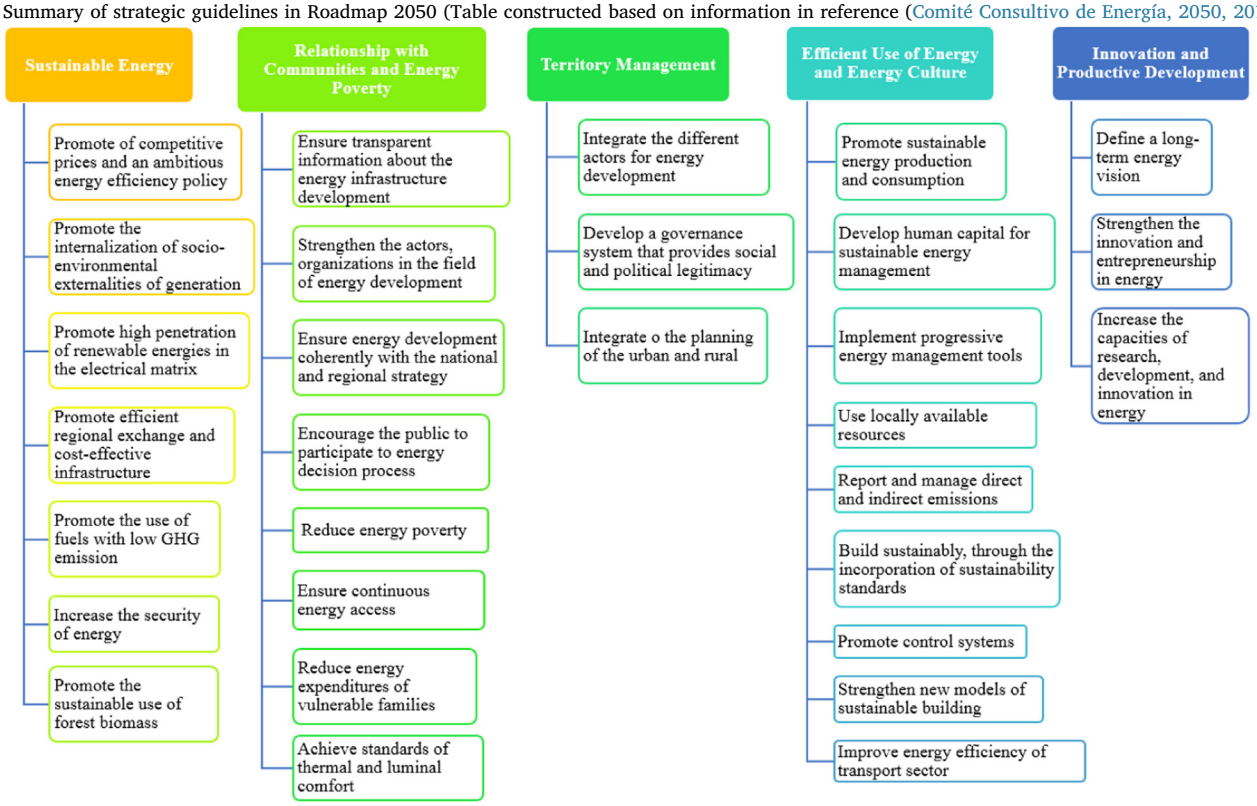


Fig. 13. Strategic axes of Roadmap 2050 study (Figure constructed based on reference (Comité Consultivo de Energía, 2050, 2015)).

Table 1
Summary of strategic guidelines in Roadmap 2050 (Table constructed based on information in reference (Comité Consultivo de Energía, 2050, 2015)).


Sustainable Energy
Promote of competitive prices and an ambitious energy efficiency policy
Promote the internalization of socio-environmental externalities of generation
Promote high penetration of renewable energies in the electrical matrix
Promote efficient regional exchange and cost-effective infrastructure
Promote the use of fuels with low GHG emission
Increase the security of energy
Promote the sustainable use of forest biomass
Relationship with Communities and Energy Poverty
Ensure transparent information about the energy infrastructure development
Strengthen the actors, organizations in the field of energy development
Ensure energy development coherently with the national and regional strategy
Encourage the public to participate to energy decision process
Reduce energy poverty
Ensure continuous energy access
Reduce energy expenditures of vulnerable families
Achieve standards of thermal and luminal comfort
Territory Management
Integrate the different actors for energy development
Develop a governance system that provides social and political legitimacy
Integrate o the planning of the urban and rural
Efficient Use of Energy and Energy Culture
Promote sustainable energy production and consumption
Develop human capital for sustainable energy management
Implement progressive energy management tools
Use locally available resources
Report and manage direct and indirect emissions
Build sustainably, through the incorporation of sustainability standards
Promote control systems
Strengthen new models of sustainable building
Improve energy efficiency of transport sector
Innovation and Productive Development
Define a long-term energy vision
Strengthen the innovation and entrepreneurship in energy
Increase the capacities of research, development, and innovation in energy

4.6. Energy 2050 (2015)

Five strategic axes and actions for the new Chilean energy policy were defined in the Road Map 2050. Then, all these decisions were combined and Chile's new energy policy was announced and published in 2015 as Energy 2050.

In that new report, Chile's energy sector would have a reliable, inclusive, competitive, and sustainable vision by the year 2050. In order to realize the new vision, the policy was built on four main pillars as listed in Table 2: quality and security of supply, energy as a driver of development, environmentally friendly energy, and energy efficiency and energy education. As a first pillar, the quality and security of supply were considered due to having a reliable energy system. Secondly, the new energy policy was based on the vision of energy as a driving force for development. Thus, in order to have growth, Chile must have complete energy development including access equality, regional planning, and competitive prices (Ministerio de Energía, 2015b).

The third pillar of the new policy was environmentally friendly energy, which meant that the development of the energy sector cannot be separated from local and global environmental impacts. Finally, energy efficiency and energy education were taken as the fourth pillar of the new policy by considering the implementation of improvements in energy efficiency (Ministerio de Energía, 2015b).

4.7. Long-term energy planning (2016–2017)

After the determination of energy policies and the main objectives for 2050, the government of Chile examined the different examples in the world to calculate the long-term energy plans quantitatively. Then, the methodology was developed for Chile to select robust energy scenarios in long-term energy planning (Centro de Energia; Universidad Adolfo Ibanez; EECG Consultores, 2017). Based on these changing factors, electricity expansion planning for each scenario was calculated, and the detailed results for generation and installed capacity for 2046 can be found in the original report. According to the scenarios developed in the study, a significant share of solar energy technologies (both concentrated solar power and photovoltaic) and wind energy were obtained for electricity capacity expansion and generation in 2046 (Ministerio de Energía, 2017).

Additionally, sectoral participation in energy consumption was studied for three different scenarios as summarized in Fig. 14. Low, medium and high energy demand and energy sectors were considered. It can be inferred that while the share of the transport sector in energy consumption reduces significantly in 2046, the contribution of industry and mining sectors increase when they are compared to the year 2015. The shares of public and commercial sector do not show essential changes in 2046.

4.8. Climate change adaptation plan (2017)

Throughout the process of assessing the development of a sustainable energy future for Chile, the Ministry of Energy conducted the preparation of a preliminary draft on a climate change adaptation plan in the energy sector of Chile with the support of the Ministry of the Environment. In this work, the impacts of climate change and adaptation measures were identified and prioritized by the contribution of national and international consultants, experts and the general public. First of all, the observed and projected climate trends in Chile were determined as follows: temperature, precipitation, external events, and the increase in sea level. After that, to assess the vulnerability of the Chilean energy sector due to climate change, a conceptual structure was developed based on the international examples by considering energy supply, energy transport (transmission and distribution), and demand. After determination of potentially affected subjects in the energy sector, action plans were developed for each impact. Finally, this work included actions to combat climate change, and also activities to promote renewable energy and energy efficiency to mitigate greenhouse gases (Ministerio del Medio Ambiente (Mitigation Action Plans and

Table 2
Actions for each pillar of Energy Policy 2050 (Table constructed based on information in reference (Ministerio de Energía, 2015b)).

Quality and Security of Supply

- Develop plans for managing risks in energy sector
- Promote a cost-effective infrastructure
- Increase the security of the supply
- Promote the exploration of Chile's hydrocarbon resources
- Promote the decentralization of energy
- Promote flexibility of the electricity system
- Ensure continuous access to the entire population

Environmentally Friendly Energy

- Promote renewable energy
- Promote sustainable hydroelectricity
- Promote fuels with low GHG emissions
- Promote the sustainable production of forest biomass
- Promote the reduction of GHG emissions
- Manage direct and indirect emissions

Energy as a Driving Force for Development

- Empower stakeholders, organizations, and communities in the area of energy development
- Promote local energy developments
- Ensure formal and pertinent public participation processes
- Reduce energy poverty
- Set standards of thermal and lighting comfort in the homes
- Integrate stakeholders, sectors for energy development.
- Integrate urban and rural
- Improve transport efficiency.
- Promote competitive prices
- Improve science, technology, and innovation in energy
- Reduce barriers to innovation and entrepreneurship

Energy Efficiency and Energy Education

- Form a robust market for energy service companies
- Progressively implement energy management tools
- Use local resources and explore potential energy savings
- Build energy efficiency standards
- Promote intelligent energy management
- Strengthen the market for efficient buildings
- Improve the energy efficiency of vehicles
- Promote more efficient transport
- Ensure clear and transparent information for citizens
- Design, implement, and monitor an energy education strategy
- Develop professional and technical human capital for the sustainable energy

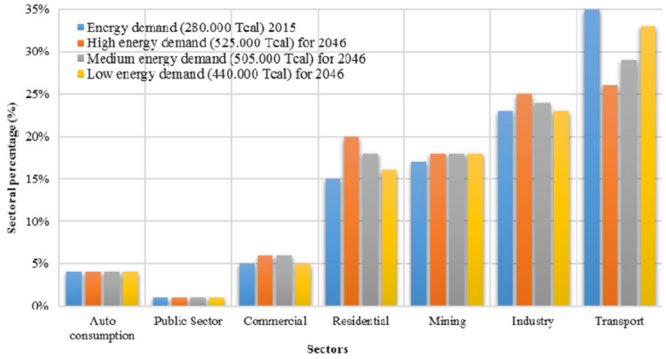


Fig. 14. Sectoral participation in energy consumption for developed scenarios (Figure constructed based on information in reference (Ministerio de Energía, 2017)).

Scenarios), 2017).

4.9. Energy Route 2018–2022 (2018)

After the elections in 2017, there was a change of the status that the new government took over in March 2018 and a new study was published that revealed the energy approach of the new government. As a result of workshops and meetings held in every region of Chile with the participation of experts and the general public, the *Energy Route* 2018–2022 was published. The main axes of the new government's route towards sustainable energy were defined with this study as follows: energy modernization, energy with a social seal, energy development, efficient transportation, low energy emissions, energy efficiency, and energy education and training.

In the report, small-scale renewable energy promotion was explicitly mentioned by aiming four times more capacity expansion of small-scale (less than 300 kW) distributed renewable generation by 2022. Additionally, for the transport sector, it was targeted that the number of electric vehicles in the country will be increased at least ten times. As of the promotion of renewable energy, the new government also declared that regulatory framework for energy efficiency in the sectors of industry, mining, transport and buildings will be developed to have a sustainable energy utilization (Ministerio de Energía, 2018).

Besides the energy route which is complementary to the long-term policy Energy 2050, *Energy Efficiency Law* project was presented to the Senate by the Ministry of Energy in 2018. The proposed law aims 7% energy saving with respect to final consumption by 2035. Thus, this law will contribute with a share of 27% to the goals proposed in the greenhouse gas mitigation plan for the energy sector (Ministerío de Energía, 2018).

4.10. Energy Scenarios: Future of energy in Chile (2018)

Energy scenario platform carried out another study which is the continuation of the previous study and which describes the most recent trends in the energy sector of Chile. As shown in Fig. 15, three "megatrends" and eleven cross-sectional trends were determined.

Moreover, depending on these three megatrends, related factors and specific trends were defined. Integration of renewable energies, electric mobility and energy efficiency are explicitly mentioned to consider for decarbonization and decontamination in the future energy matrix in Chile. Also, micro-grids, smart grids and energy storage are cited in the study as a future specific trend for decentralization and distributed energy, which are significant expected developments in the future (Escenarios energeticos, 2018).

In order to conclude this section, in parallel with worldwide actions for climate change adaptation, Chile has undertaken several energy studies from 2011 to 2018. These significant works were summarized in this section. After this review of the important historical background of energy policy development, Chile´s energy and environmental goals in the upcoming years will be discussed in the following section.

5. Nationally determined contributions and principal energy targets of Chile

In this section, the revised nationally determined contributions and principal energy targets of Chile for 2035 and 2050 were mentioned

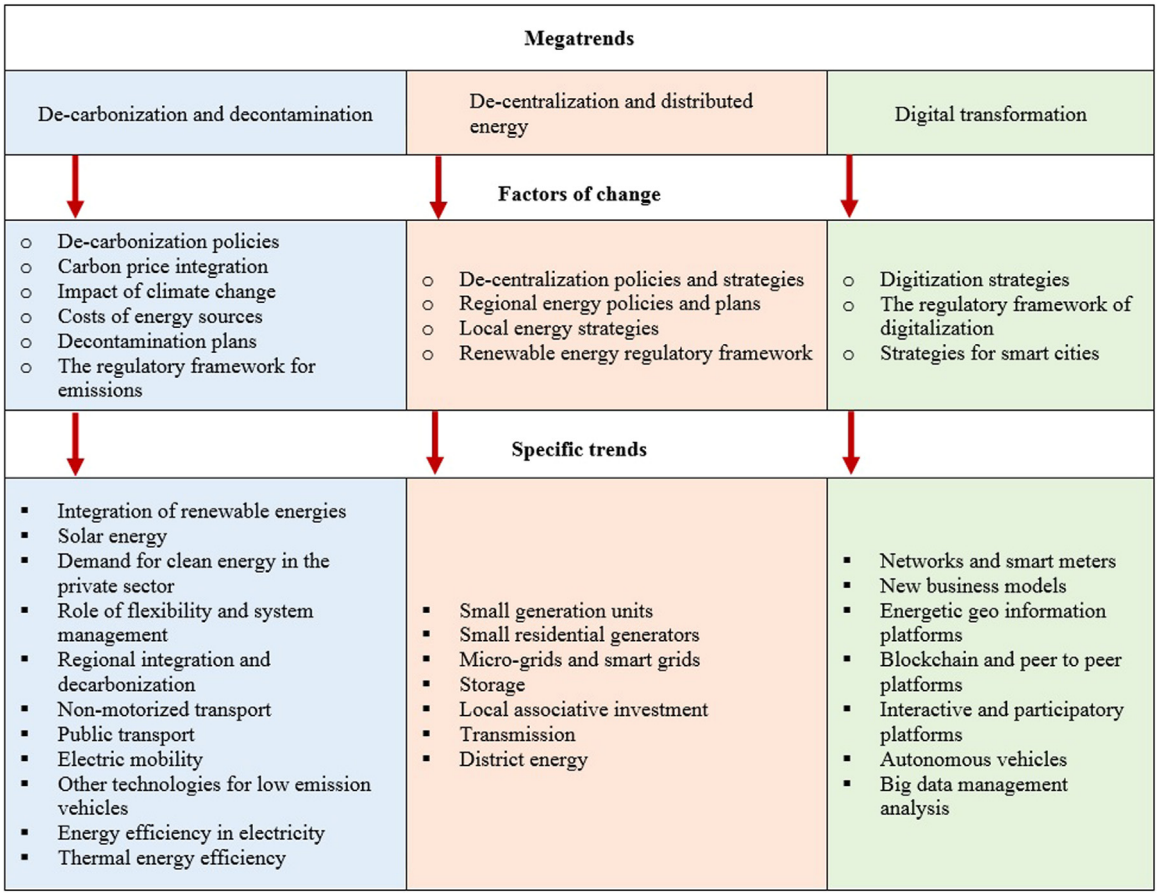


Fig. 15. Aspects that shape the future of energy in Chile (Figure constructed based on reference (Escenarios energeticos, 2018).

and listed.

Worldwide, the majority of countries determined their Intended Nationally Determined Contributions, which became Nationally Determined Contributions (NDCs) after ratifying the Paris Agreement (Griffiths, 2017). In 2015, Chile presented its intended national contribution to the United Nations Framework Convention on Climate Change. Chile's NDCs depended on five basic pillars: mitigation, adaptation, capacity building and strengthening, technology development and transfer, and financing. NDCs on mitigation were committed to two main targets: an unconditional target to reduce the GHG-emissions intensity of the economy by 30% below the 2007 level by 2030, and a conditional target of a 35–45% reduction in GHG emissions intensity subject to international financial support.

In addition to GHG emissions, Chile committed to the sustainable development and recovery of 100,000 ha of forest land, mainly native, which will account for greenhouse gas sequestrations and reductions of an annual equivalent of around 600,000 of CO_2 as of 2030 (The Committee of Ministers for Sustainability and Climate Change, 2015).

Moreover, in Energy Policy 2050 (Ministerio de Energía, 2015b), principal energy objectives were defined for the years 2035 and 2050, as illustrated in Table 3. For 2035, major targets were defined by considering Chile's interconnection with other countries, limits on electricity outages, energy access, renewable energy electricity generation targets, emission targets, energy efficiency, and regulations in transportation.

In addition to the main concerns for 2035, land use and GDP growth were taken into account in devising the principal energy goals for 2050. Between these targets, electricity generation from renewable energy sources and the implementation of energy efficiency measures by 100% of the large energy consumers are expected to have an important contribution to reaching energy and environmental objectives.

Finally, in addition to environmental and energy targets due to climate change concern, Chile should consider other issues among the seventeen sustainable development goals and take actions to improve its worldwide score by taking into account the most recent challenge of setting more stringent standards aimed at limiting global warming to 1.5 °C (IPCC, 2018).

6. Assessment and discussion

From the revision of energy policy development in Chile (Sections 4 and 5), it is understood that the integration of renewable energy and energy efficiency are explicitly mentioned to consider for decarbonization and decontamination in the future energy matrix in Chile. Therefore, in this section, current energy policy instruments related to renewable energy and energy efficiency in the world and in Chile were addressed and evaluated by using a comparative assessment process. This analysis was realized to understand how renewable energy is promoted in the world and how it is being achieved in Chile. Also, required policy instruments were briefly identified for each sector. After the assessment process, potential future energy policy challenges are determined and explained to guide decision makers to create sustainable future energy policies.

6.1. Assessment of energy policy instruments

Energy policy instruments are governments' actions to stimulate and try to achieve different potential energy policy objectives. These instruments must be specifically chosen for the country's unique situation by considering environmental effectiveness, cost-effectiveness, complexity, distributional issues, institutional feasibility and political issues, government costs, and the opportunity to leverage international

Table 3
Principal energy goals for 2035 and 2050 from Energy 2050 (Table constructed based on information in reference (Ministerio de Energía, 2015b)).

2035	2050
Chile's interconnection with the other South American countries	
Electricity outages less than 4 h/year	Electricity outages less than 1 h/year
100% quality access to energy services	100% quality access to energy services
Lowest average residential and industrial electricity prices	Lowest average residential and industrial electricity prices
At least 60% of the electricity generation from renewable energy	At least 70% of the electricity generation from renewable energy
By 2030, at least 30% GHG emissions reduction compared to 2007	International and national GHG emissions reduction targets
Efficient use of energy	100% of new buildings with OECD standards for efficient construction
Promote Energy efficiency for public transportation systems	100% energy efficient appliances and equipment
Regulate forest biomass utilization	Develop Energy culture for citizens

funding. Also, it is not a simple process to understand the interactions among different individual energy policy instruments; thus it is challenging to select a proper combination of policy instruments (Benitez, 2012). In particular, when combining instruments, it is important to analyse whether the combination of several policy instruments has more added value than other combinations or single instruments (Löschel and Zew, 2012; Oikonomou et al., 2014).

In most of the studies for Chile reviewed in this paper, it is very clear that the contribution of renewable energy and energy efficiency to the low-carbon economy of 2050 has been emphasized strongly. Therefore, in this section, current and appropriate energy policy instruments for the different Chilean energy sectors are discussed by considering the important pillars of Energy Policy 2050.

6.1.1. The promotion of renewable energy

Promoting renewable energy is one of the key actions to fight against climate change worldwide. Political and scientific committees agree that renewable energy has to perform an essential role in the pathway to a low-carbon economy (Löschel and Zew, 2012). Besides developed countries like Germany, Spain, and the United States, developing countries such as India and China have recently started to significantly support renewable energy (Thapar et al., 2016). Depending on the country, some policy instruments are required in order to increase renewable energy share and make it competitive against conventional technologies. In different studies, various classifications can be found for energy policy instruments (Benitez, 2012; IRENA, 2012; Oikonomou and Jepma, 2008; Park, 2006; Perrels, 2001; Regulation Body of Knowledge, n.d.; Thapar et al., 2016; Warbroek, 2013). The key energy policy instruments used worldwide in support of the deployment of renewable power are these: fiscal incentives, public finance, and regulations (Benitez, 2012; Elizondo Azuela and Barroso, 2011; IRENA, 2012; Thapar et al., 2016).

FITs, tax incentives, and tradable green certificates are support mechanisms commonly used by governments to promote renewable energy (Abolhosseini and Heshmati, 2014; Thapar et al., 2016). FITs, quotas, tendering, and tax measures are especially being utilized by European countries to increase the share of electricity produced from renewable energy sources (Löschel and Zew, 2012; Ragwitz et al., 2006). However, it has been shown that although FITs are more effective (Warbroek, 2013), they can be relatively expensive when compared to quota mechanisms (Elizondo Azuela and Barroso, 2011). Further, renewable energy deployment has accelerated considerably in various Latin America countries such as Mexico, Chile, and Brazil (IRENA, 2015a).

In contrast to the EU countries, Chile is one of the countries that have been successful in the promotion of renewable electricity production without fiscal incentives or FITs. The development of renewable energy capacity in Chile without any incentives is remarkable. Chile currently has a renewable energy target, quota obligation, auctions, net metering, certificate system, and grid access, as well as some fiscal incentives for rural areas in electricity production (IRENA, 2015a, 2015b). In 2013, Chile set a target to produce 20% of its electricity from renewable energy sources by 2025 (IRENA, 2015b). After this short-term target, a new long-term target was set in Energy 2050 (Ministerio de Energía, 2015b) study: at least 70% of the electricity generated in Chile will come from renewable energy sources by 2050. Based on its targets, Chile has a quota obligation as the main policy instrument.

In the Chilean Renewable Energy Law signed in 2013 (Ministerio de Economía, 2013), renewable energy quotas were defined as 12% in 2020, 18% in 2024, and 20% in 2025 (excluding large hydro). Auctions for electricity production are another important support mechanism for Chile. They allow all types of renewable energy generators to have 10-year power purchase agreements with distribution companies. Also, Chile uses net metering, which permits consumers to produce their own electricity from renewable energy sources and inject extra generation into the grid. Additionally, the current law allows renewable energy generators under 9 MW to be exempt from grid access fees. Moreover, Chile provides technology-specific support and regulations especially for biomass, geothermal (exploration and exploitation of resources), concentrated solar power, solar roof application, and small hydro (IRENA, 2015b, 2015a).

Furthermore, a carbon tax was passed in September 2014 with the tax reform law 20.780, which states that a yearly tax of 5 USD/tonneCO_2 will be applied to the emissions of power plants exceeding 50 MW capacity (except biomass) (IRENA, 2015a; The Committee of Ministers for Sustainability and Climate Change, 2015). The only direct support in the form of subsidies in Chile is given for solar heating in the reconstruction of disaster-affected regions such as Arica, Iquique, and Valparaíso (IRENA, 2015a, 2015b). In the transport sector, Chile has tax-exempt fiscal incentives for biodiesel and bioethanol, and regulations for mixing bioethanol and biodiesel with gasoline and diesel at 2% and 5%, respectively. Finally, Chile provides some support for electricity access in rural and indigenous regions, PV production in countryside, and solar energy for agriculture (IRENA, 2015b).

It can be seen that there are several efforts in almost all sectors in Chile in terms of deployment of renewable energy. However, in order to reach the targets proposed, other instruments could also be considered by the government as presented in Table 4. For instance, mining activities, which take place in the north of Chile, are characterized by very significant energy consumption as compared to other sectors. Therefore, it is worthwhile to investigate specially designed policy instruments to exploit potential synergies between the mining and solar power industries. For example, tax credits and production-based incentives can be studied to lower the levelized cost of energy and reduce the governmental cost for concentrated solar power technologies in Chile (Simsek et al., 2018). Also, priority or guaranteed access to networks, priority dispatch, tax credits and soft loans should be considered for mining and industry sectors. The residential, public and commercial sectors can be supported with incentives for rooftop photovoltaics to create more distributed self-producers. Finally, new mandatory and economic instruments could be studied for the transport sector to be prepared for the upcoming electric-transportation revolution.

Table 4
Energy policy instruments used in the world and in Chile to promote renewable energy.

Energy policy instruments used in the world to promote renewable energy	Energy policy instruments status quo in Chile	Instruments to consider for energy sectors
Fiscal incentives (grants, energy production payments, rebates, tax credits, tax concessions/exemptions) **Public finance** (investments, guarantees, loans, public procurement) **Regulations** (renewable portfolio standards/quota obligations or mandates, auctions, tendering, bidding, feed-in-tariffs (FITs), premium payment FITs, green energy purchasing, green labelling, net metering, priority or guaranteed access to networks, priority dispatch)	• Renewable energy target • Quota obligation • Auctions • Net metering • Certificate system • Priority grid access • Fiscal incentives for rural areas in electricity production • Carbon tax • Subsidies for disaster-affected regions • Tax-exempt fiscal incentives for biodiesel and bioethanol • Regulations for mixing bioethanol and biodiesel • Direct support for electricity access in rural and indigenous regions and agriculture	**Mining and Industry:** • Priority or guaranteed access to networks • Priority dispatch • Tax credits • Production-based incentives • Soft loans **Residential:** • Grants • Tax exemptions • Loans • Green energy purchasing • Green labelling • Priority access to the grid **Commercial and Public:** • Tax credits • Loans • Green labelling • Priority or guaranteed access to networks • Priority dispatch **Transportation** • Tax credits/exemptions • Loans • Green labelling • Mandatory certification • Regulations

6.1.2. Energy efficiency

Energy efficiency is another significant issue in aiming towards a sustainable energy future. Both industrialized and developing countries are trying to adopt energy efficiency in several energy sectors (Jedlicka et al., 2005; Löschel and Zew, 2012). Denmark is a good example of having since 1997 an obligatory building energy-efficiency label program. Additionally, countries such as China, Italy, and the United States have policy instruments for promoting energy-efficient programs in the building sector. The approach to energy efficiency promotion shows the changes between countries.

The literature features mostly building/residential energy efficiency studies due to a relatively high potential for energy savings from reduced inefficiency (Boza-Kiss et al., 2013; Bye et al., 2018; Filippini et al., 2014; Kern et al., 2017; Madlener and Stagl, 2005; Shen et al., 2016). For instance, Australia, Japan, and China have more mandatory instruments, while the EU has adjusted a large number of both economic instruments and mandatory instruments in order to promote energy efficiency in buildings. On the other hand, the United States has preferred voluntary instruments to increase energy efficiency activities. Depending on the country, the implementation of mandatory, economic, and voluntary instruments can encounter several barriers and complications.

To minimize the risks in practice, a combination of energy efficiency policy instruments should be considered by governments (Kern et al., 2017; Shen et al., 2016). Not only energy efficiency instruments but also energy efficiency and renewable energy promotion instruments can be combined to reach environmental and energy targets (Oikonomou et al., 2014). Also, the costs of investing in energy efficiency improvements must be studied for particular countries and their conditions (Bye et al., 2018). A study about building energy efficiency stated that product energy performance standards and their combination with product labels showed considerably better results regarding environmental and cost-effectiveness than any other instrument. Building codes have been the most utilized policy instruments, chosen by more than thirty countries (Boza-Kiss et al., 2013; Karlstrøm and Ryghaug, 2015). Moreover, for the EU residential sector, financial incentives and energy performance standards have shown significant effects in stimulating energy efficiency improvement, although informative measures such as labelling and educational campaigns have not been shown to have noteworthy results (Filippini et al., 2014).

In order to aim toward a sustainable energy future, energy efficiency has gained in importance for Chile. In 2009, the law (20.420) of the creation of Energy Ministry of Chile also included the decision to establish minimum energy performance standards (MEPS) and definition of the products that must have an energy efficiency label (Biblioteca del Congreso Nacional de Chile, 2012a). After that, in 2012, a decree about regulations to establish the procedure for setting MEPS and their application was launched (Biblioteca del Congreso Nacional de Chile, 2012b). Also, stimulation of energy efficiency in several sectors was mentioned as one of the main pillars of the new energy policy of Chile (Gobierno de Chile, 2014; Ministerio de Energía, 2015b, 2014).

For energy efficiency issues, the Energy Ministry collaborates with other ministries. Additionally, Energy Sustainability Agency (Agencia de Sostenibilidad Energética) is a non-profit public-private foundation that promotes energy efficiency by providing education and dissemination programs (Morgan et al., 2014). To reach the energy efficiency goals of 2035 and 2050, the government has progressively increased its budget for energy efficiency from USD 50 million in 2012 to USD 109 million in 2015 (IEA, 2018).

In the Chilean case, not only the residential sector but also the mining, transport, and industry sectors should be considered for energy efficiency actions to make significant contributions toward lowering global emissions as shown in Table 5. Chile has mandatory energy efficiency labelling for appliances, which is quite successful (Biblioteca del Congreso Nacional de Chile, 2012b). It also has energy codes and efficiency standards for buildings (social housing and private residential buildings) to increase energy performance. However, there are no regulations for non-residential and commercial buildings. Further, firewood is an important energy source for households in the south of Chile. Therefore, policies, regulations, and financial incentives are applied in order to support the efficient and clean use of firewood. In the Chilean industrial sector, besides MEPS, only voluntary actions are found in terms of energy efficiency. In the transport sector, an energy efficiency label for new light-duty vehicles has been mandatory since

Table 5
Energy policy instruments used in the world and in Chile to promote energy efficiency.

Energy policy instruments used in the world to promote energy efficiency	Energy policy instruments status quo in Chile	Instruments to consider for energy sectors
Mandatory instruments (laws, regulations, codes, and standards) **Economic instruments** (subsidies, taxes, and loan incentives) **Voluntary instruments** (R&D, certifications and labels, governmental services)	• Voluntary actions such as information and awareness campaigns • Minimum energy performance standards • Mandatory energy efficiency labelling for appliances • Energy codes and efficiency standards for buildings (social housing and private residential buildings) • Mandatory labelling for new light-duty vehicles	**Mining and Industry:** • Regulations • Codes and standards • Certifications and labels **Residential:** • Laws • Regulations • Codes and standards • Subsidies • Tax incentives • Loans • Certifications and labels **Commercial and Public:** • Laws • Regulations • Codes and standards • Loans • Certifications and labels **Transportation** • Laws • Regulations • Codes and standards • Subsidies • Tax incentives • Loans • Certifications and labels

2013. However, to promote energy efficiency successfully, besides voluntary instruments, mandatory and economic support mechanisms are required for specific sectors. More laws, regulations, codes, and standards must be investigated by the government for the industry, mining, and transport sectors and also economic and mandatory mechanisms for residential sector to reach the target of reducing energy consumption by 20% (against 2010) by 2025 (IEA, 2018).

6.2. Energy policy challenges for the future

Energy policy development is an iterative process. The developed policies need to be improved and adapted as lessons are learned and conditions evolve. Further, decision makers face many challenges when making adjustments in energy policy. In this section, some important challenges are discussed in terms of potential future energy policy actions.

6.2.1. Variable renewable energy

Rapidly developing renewable energy technologies and storage systems are significantly affecting the renewable energy contribution to energy planning. Decreasing costs will accelerate the implementation of renewable energy. Thus, incentives for renewable energy may not be needed, financial support must be limited, and new regulations should be considered depending on cost reduction of technologies. Chile is an example of the successful promotion of renewable energy without FITs, due to its high potential. However, cost reduction in energy storage and ocean-based energy production technologies can also be suitable for Chile, and new policies can be formed based on these developments in the future. One of the main challenges of variable renewable energy is that it needs to be properly coupled with flexible resources that can absorb their uncertainty and daily changes. This makes long-term planning and the design of effective energy markets and associated incentives a major challenge. Designing effective policy instruments to face this situation is of utmost importance (Bird et al., 2013; Miller and Cox, 2014; Stram, 2016).

6.2.2. Distributed energy resources

Technological progress, environmental concerns, and growing demand increase the number of distributed energy resources, which include small-scale power generation units and batteries, for example. Micro-turbines, PV panels, small-scale wind turbines, battery storage, and fuel cells are all considered as distributed energy resources. These resources must be integrated carefully by considering local energy markets and microgrids to provide an alternative for centralized energy production and long-distance energy transmission (Driesen and Belmans, 2006). Energy instruments like net metering must be redesigned for the many actors who would comprise small-scale producers. Chile has a long and narrow shape, which means that its geography requires long and expensive energy transmission. Thus, microgrids can further play an important role in providing reliable energy access for isolated communities. In particular, the south of Chile has various small islands where small communities live isolated from the main power grid (Mohd et al., 2008; Poudineh and Jamasb, 2014). Thus, policy instruments for the promotion of distributed energy resources can lead to substantial solutions for society.

6.2.3. Electric transportation and general electrification

In 2016, new registrations of electric cars reached a very high number, with over 750,000 sales worldwide since 2010. The global stock of electric cars exceeded 2 million vehicles in 2016; in 2015 this was approximately 1 million. Due to the transformation of electric transportation, oil consumption in the energy balance of countries is expected to be reduced. Thus, electricity demand will increase considerably by affecting resource procurement management (European Comission, 2017; IEA, 2017). Besides transportation, the revolution of electrification in heating and power will be another essential issue that concerns many sectors. Chile has a high oil consumer transportation sector. Also, heating from biomass is a common method in the countryside. Therefore, in order to keep up the electrification transformation, which is required to reduce GHG emissions, policies must be reformed to prepare for this adaptation and to extract the benefits from these important changes.

6.2.4. Demand response and aggregators

Instead of supplying more energy in high-demand times, demand itself can be managed to a certain extent through proper incentives and

communication infrastructure to reduce consumption when it is more critical. This mechanism is called demand response, and it can significantly reduce emissions, provide for the efficient use of energy, and balance the operational costs. Especially in the integration of renewable energy, demand response is an effective management strategy to support the injections from these fluctuating resources. This approach could be emphatically considered for the Chilean industry and mining sectors to produce efficient future demand and supply planning. Thus, the design of proper policy instruments to generate value from the demand response potential is also a very important challenge (Albadi and El-Saadany, 2007; Poudineh and Jamasb, 2014; Su and Kirschen, 2009).

6.2.5. Climate change impact and resilience

Besides reliability, resilience is another essential concept to be considered in future energy systems. Due to climate change, some variations in the potential of hydro sources, as well as temperature and wind profile changes, are expected in future years (Panteli et al., 2017; Panteli and Mancarella, 2015). In addition to changes due to global warming, energy systems must be prepared for disasters such as tsunami, earthquakes, volcanic eruptions, and wildfires. Chile is a country with a high-risk potential for natural disasters. In recent history, it has had several high-magnitude earthquakes, tsunamis following earthquakes, the eruption of active volcanos, and wildfires, especially in summer time due to high temperature. All these types of disasters affect the secure energy supply. Thus, the Chilean energy system must be supported by policies to be prepared for quick changes and unexpected disasters.

7. Conclusion and policy implications

Oil, coal, natural gas, biomass, hydro, solar, and wind sources are the primary energy supplies of Chile. These sources are utilized in five main sectors in the country. Transport and industry have the major shares in total energy consumption, and mining activities in the northern regions are also heavily energy intensive. Chile mostly depends on imports for its domestic energy supply—almost 65% in the most recent years. It has noteworthy renewable energy potential for sources. The formation of the Ministry of Energy in 2010, dependence on imports for domestic energy supply, the significant transformation in the international energy market, global concerns about climate change, and the availability and competitiveness of renewable energy technologies have forced Chile to implement sustainable long-term energy planning and policies.

Promoting renewable energy and energy efficiency are popular ways for countries to reach their energy and environmental goals and for decarbonization and decontamination in the future energy matrix. FITs are the most popular renewable energy support mechanisms in the world. However, Chile became successful in promoting renewable electricity production without fiscal incentives or FITs. Nevertheless, encouraging the mining and industry sector with obligatory regulations, using public finance for the residential sector, and mandatory economic instruments for the transport sector can be useful to increase the renewable energy share in all energy sectors.

Adoption of energy efficiency in several energy sectors is another substantial matter to achieve a sustainable energy future. Chile has mandatory energy efficiency labelling for appliances, energy codes, and efficiency standards for social housing and private residential buildings. However, there are no regulations for non-residential and commercial buildings and the efficient and clean use of firewood. In the Chilean industrial sector, only voluntary actions are found. In the transport sector, an energy efficiency label for new light-duty vehicles has been mandatory since 2013. Chile has mostly voluntary support mechanisms for energy efficiency.

Nonetheless, mandatory and economic support mechanisms are also necessary for specific sectors. More laws, regulations, codes, and standards must be implemented by the government in the industry, mining, and transport sectors to reach the national target. The combination of renewable energy instruments with energy efficiency instruments can produce a substantial impact. This work can provide meaningful thought for decision makers while they develop long-term sustainable energy plans so that Chile can reach energy and environmental goals. Further studies are planned to develop a long-term demand and supply model of the Chilean energy sector by creating several scenarios with different energy policy instruments and evaluating the impacts of these instruments on energy and environmental targets.

Acknowledgement

Y. Simsek acknowledges the financial support of the Chilean National Commission for Scientific and Technological Research under scholarship CONICYT-PCHA/ Doctorado Nacional/ 2018-21181469.

The authors thank Dr. Javier Bustos for valuable discussions that helped to articulate this paper.

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